3GPP TSG-RAN WG1 #NR **R1-1700645**
16th – 20th Jan 2017
Spokane, US

Agenda item: 5.1.5.1

Source: National Taiwan University

Title: Evaluation on double QC-LDPC codes with degree-3 for URLLC

Document for: Discussion

1 Introduction

This contribution follows the RAN1-#87[1] conclusion and agreement and further study should be prioritized for LDPC codes.

Conclusion:

- One aspect that should be considered further for the NR LDPC design is the lifting size definition:
  - E.g. the lifting size $z = c*2^d$, where c is chosen from a set C of positive integers and, for each value of c, d is taken from the set D = [0,1, 2, 3, 4, 5, 6, 7, 8]
    - FFS the set C

Agreement:

- Code extension of a parity-check matrix is used for IR HARQ/rate-matching support
  - Use lower-triangular extension, which includes diagonal-extension as a special case
- For the QC-LDPC design, the non-zero sub-blocks have circulant weight <=2
  - Circulant weight is the number of superimposed circularly shifted Z×Z identity matrices
- In parity check matrix design, the highest code rate ($R_{max,j}$) to design j-th H matrix for is
  - $R_{max,j}$ <=8/9
  - $R_{max,j}$ is the code rate of the j-th H matrix before code extension is applied ($0 \le j < J$)
  - $R_{max,j}$ is the code rate after accounting for the built-in puncturing, if this is applied in H matrix design
  - Rate matching to support transmission code rate higher than $R_{max,j}$ is not precluded

We present and summarize double quasi-cyclic low-density parity check (DQC-LDPC) code with degree-3 following [2]. These codes are designed as z = 64 or 16. With the constraint of the same circulant size, the design could achieve BLER down to 10^-5 from short to long block length with IR-HARQ support and low decoding complexity.

2 Design Result and Summary

Coding scheme selection of 5G new radio for eMBB, URLLC and mMTC consider the metrics of performance, implementation complexity, latency (decoding/encoding), flexibility (e.g., variable code length, code rate, HARQ (as applicable for particular scenario(s))). The LDPC code has been selected as the promising candidate according to the system simulation.

The DQC-LDPC is a special form of the classical QC-LDPC codes in the parity check matrix. The DQC code features double layers of circulant matrices (or circulant of circulants). Fig. 1 shows an example of double circulant in the parity matrix on the left submatrix of **H**. For convenience, "*" is used to denote the null matrix of size Q x Q. As in QC-LDPC code, each small square blocks (or submatrices) of size Q x Q are the null matrix (denoted by "*") or circulant permutation (right-shifted identity) matrices. A square collection of the small square blocks forms the outer layer of circulant matrix in **H**. The unique feature helps to encode the parity with double shift register array.

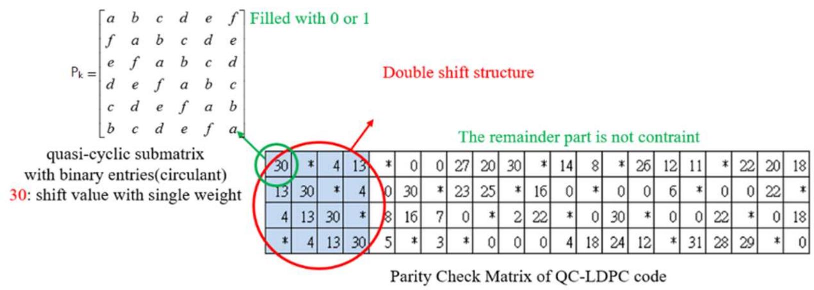

Fig. 1. Example of DQC-LDPC where the parity matrix is shaded on the left and the information is on the right.

The double QC-LDPC codes with degree-3 features superior support on these metrics.

1. **Correction:** The following figures show the typical BLER the code family. For each code , the BLER down to 10^{-5} can be achieved.
2. **Implementation Complexity:** The number of degrees of the whole PCM indicates the codec complexity. The code family we propose has the fixed low degrees = 3 (column-degree)*N(codeword length).
3. **Latency and throughput:** The code family we propose has the regular structure in the parity check matrix. If processing unit allow 2^p-dim parallel processing, the decoder has predictable latency: N(codeword length)/2^p(parallel processing)*(average iteration) cycles. The final throughput then scales with the working clock frequency of decoder.
4. **Flexibility:** The following figures also show the flexibility of the code family with the code rate from 1/4 to 8/9, and information length is from 100 bits to 8000 bits.
5. **IR-HARQ support:** IR-HARQ scheme is also supported by code extension.

The following figures are the family of DQC-LDPC codes with circulant size z =16 with PCM degree-3:

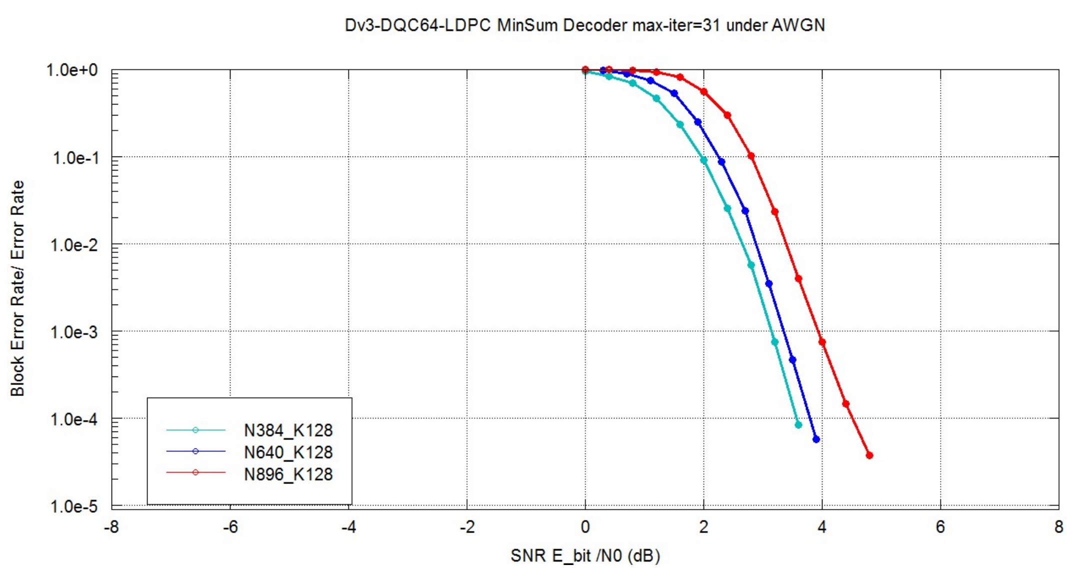

Fig. 1. DQC-LDPC codes with circulant size z =16 with PCM degree-3 and K = 128.

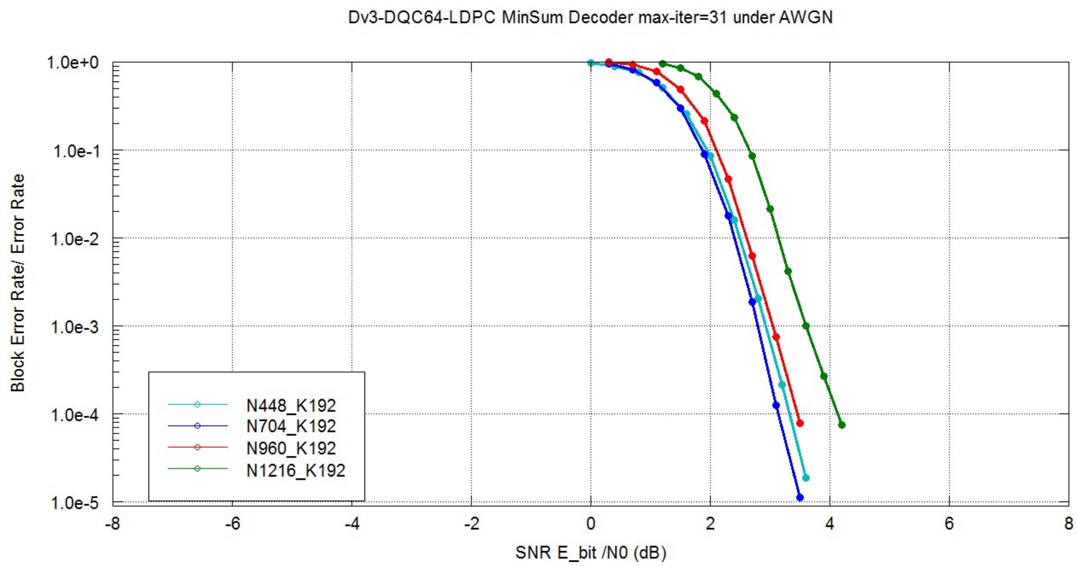

Fig. 2. DQC-LDPC codes with circulant size z =16 with PCM degree-3 and K = 192.

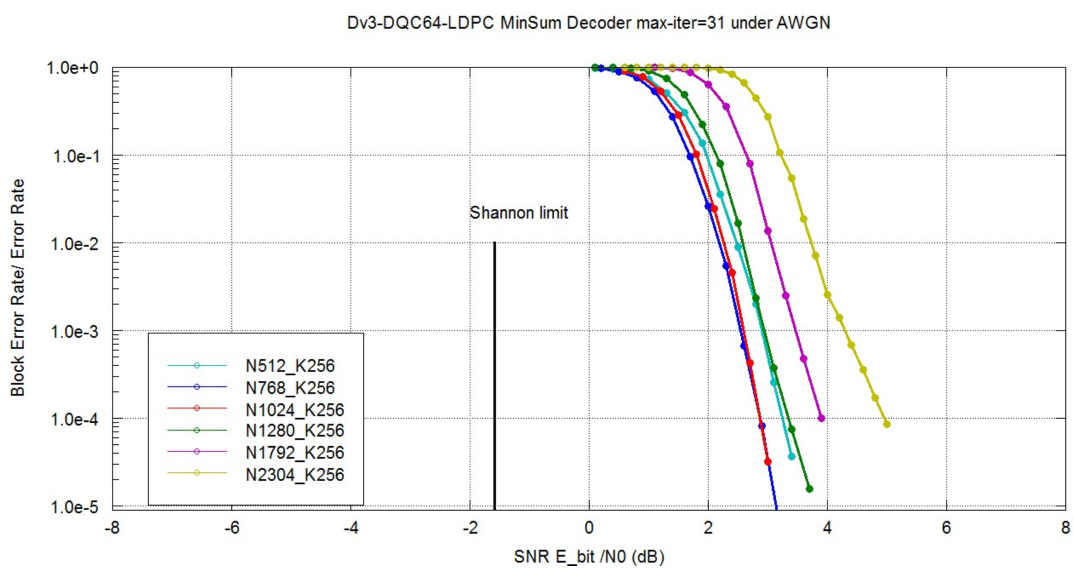

Fig. 3. DQC-LDPC codes with circulant size z =16 with PCM degree-3 and K = 256.

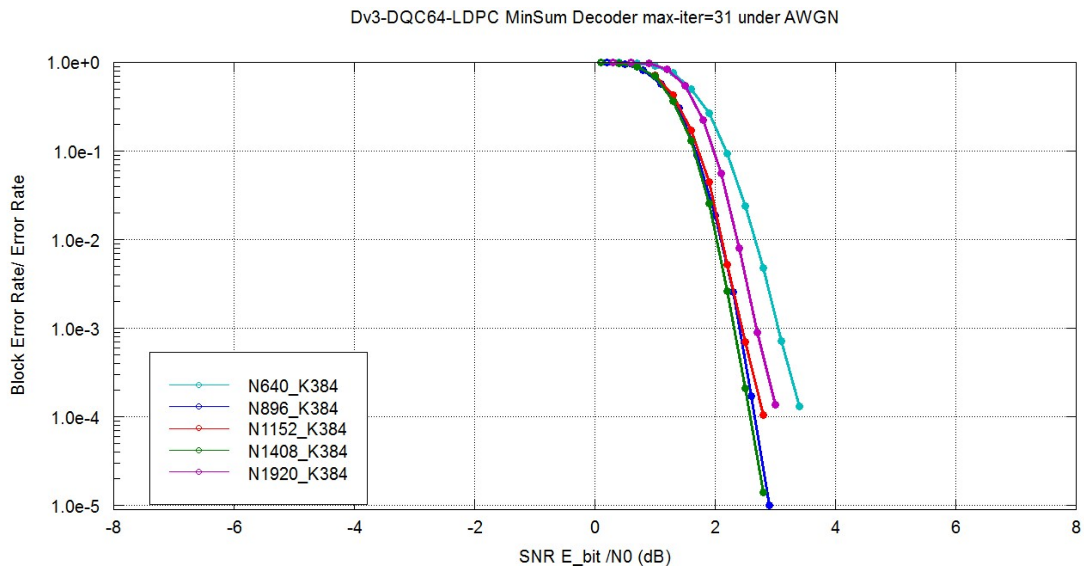

Fig. 4. DQC-LDPC codes with circulant size z =16 with PCM degree-3 and K = 384.

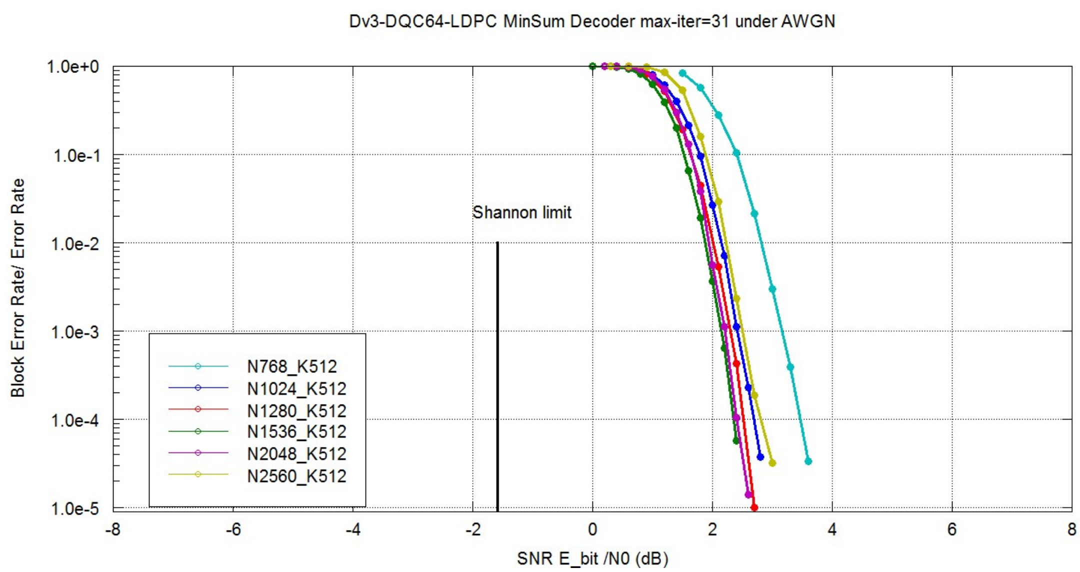

Fig. 5. DQC-LDPC codes with circulant size z =16 with PCM degree-3 and K = 512.

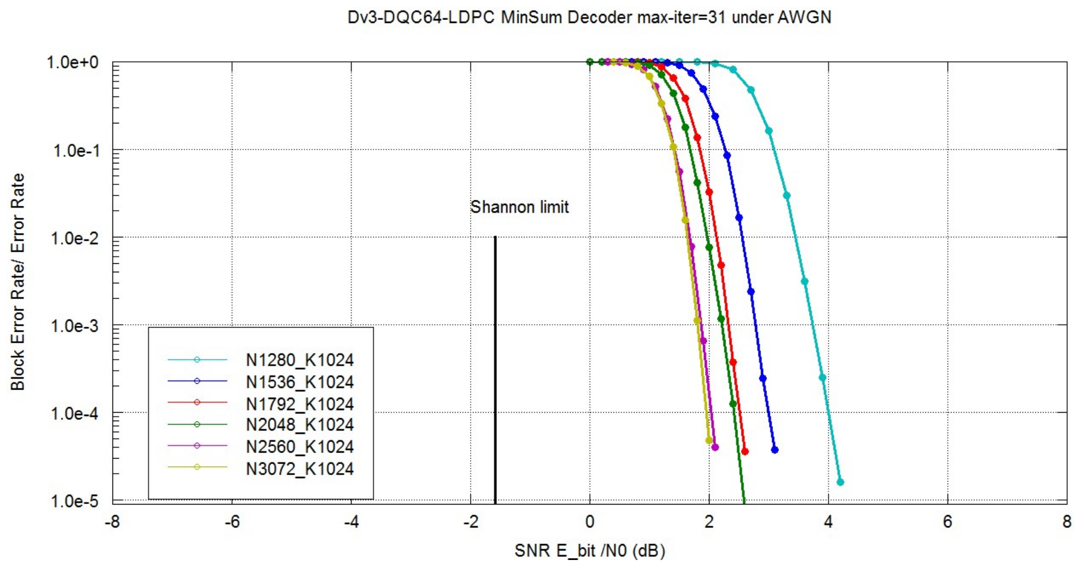

Fig. 6. DQC-LDPC codes with circulant size z =16 with PCM degree-3 and K = 1024.

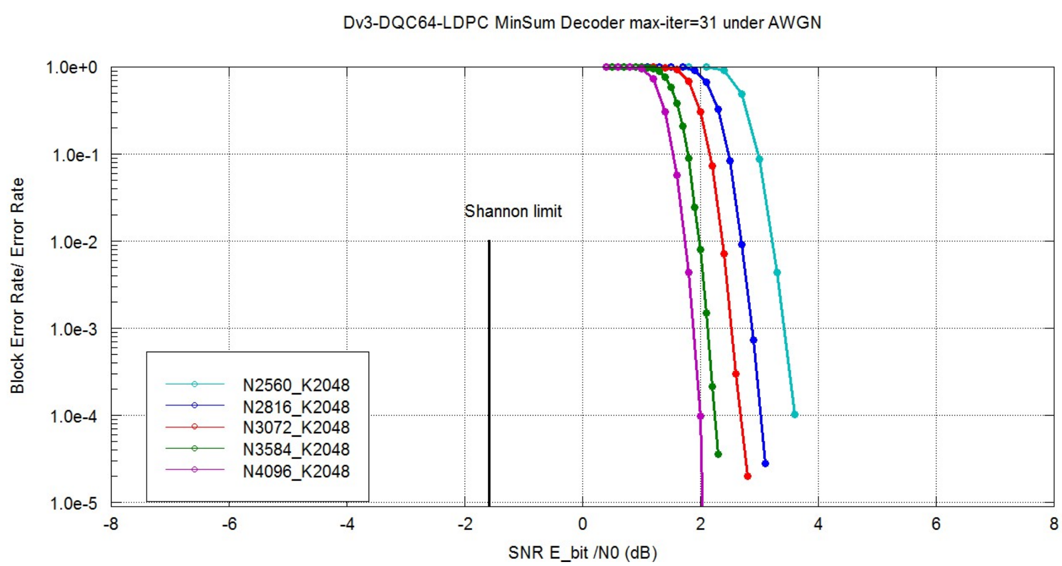

Fig. 7. DQC-LDPC codes with circulant size z =16 with PCM degree-3 and K = 2048.

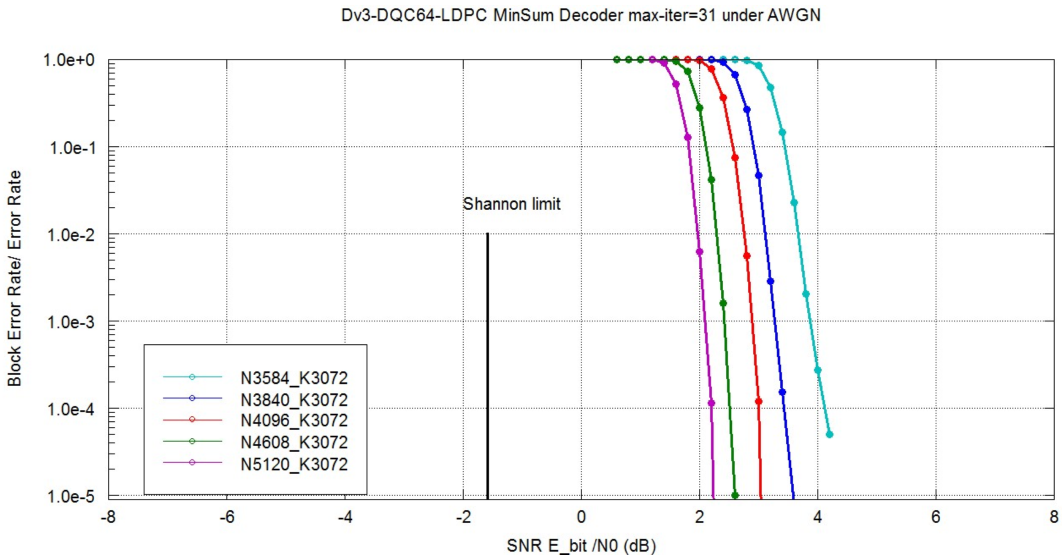

Fig. 8. DQC-LDPC codes with circulant size z =16 with PCM degree-3 and K = 3072.

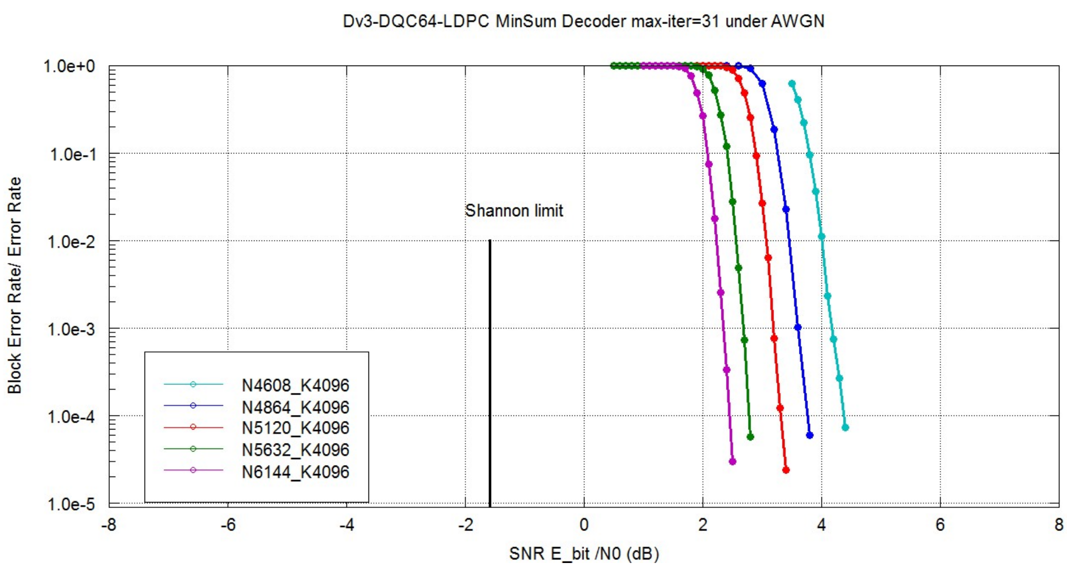

Fig. 9. DQC-LDPC codes with circulant size z =16 with PCM degree-3 and K = 4096.

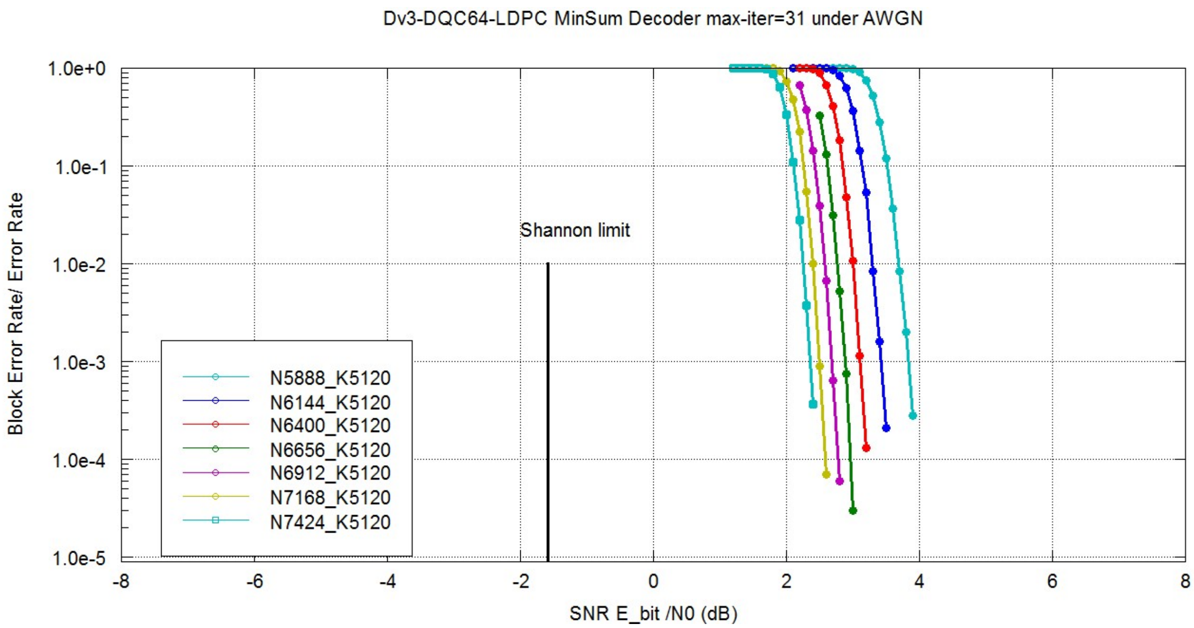

Fig. 10. DQC-LDPC codes with circulant size z =16 with PCM degree-3 and K = 5120.

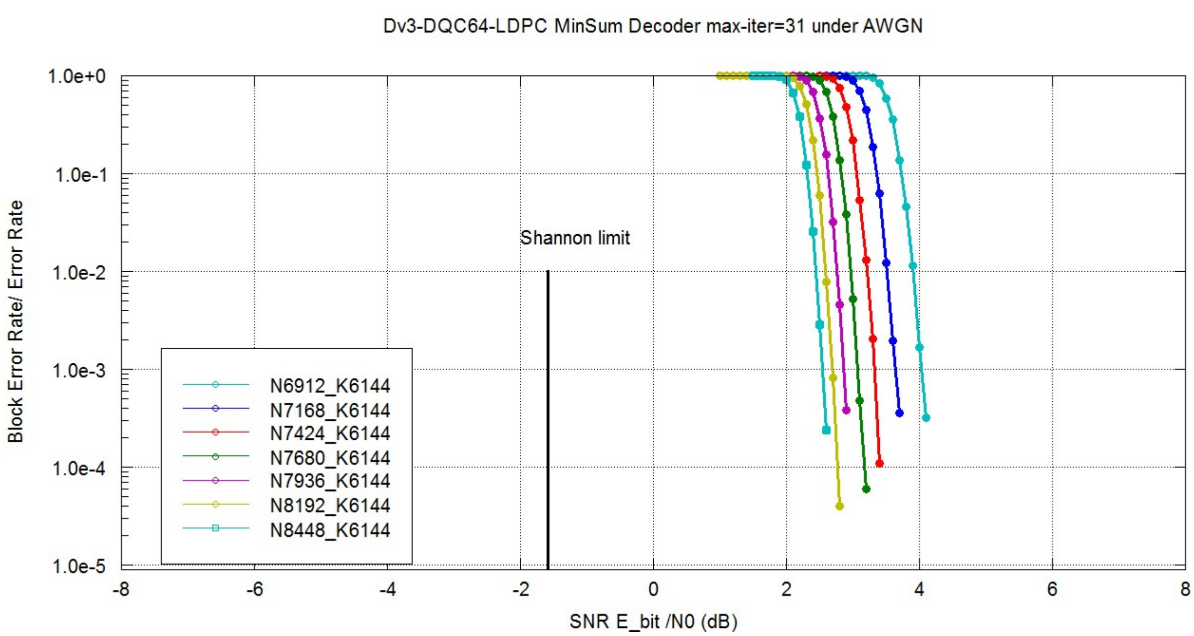

Fig. 11. DQC-LDPC codes with circulant size z =16 with PCM degree-3 and K = 6144.

3 Conclusions

Proposal 1: Double QC-LDPC codes with degree-3 can provide achieve BLER down to 10^-5 from short to long block length with IR-HARQ support and low decoding complexity.

4 References

[1] R1-1613710, Chairman's Notes of AI 7.1.5 on channel coding and modulation for NR, 3GPP RAN1 meeting #87, Reno, Nevada, Nov. 2016.

[2] R1-1609708, "Discussion of QC-LDPC code design with regular degree-3 for NR", National Taiwan University, 3GPP RAN1 meeting #86bis, Lisbon, Portugal.